

Calculation of Radiological Preliminary Remediation Goals in Soil for an Industrial Worker Exposure Scenario for the 100 Areas and 300 Area Remedial Investigation/Feasibility Study Reports

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

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Determine radiological soil preliminary remediation goals that will be used to support the 100 Areas and 300 Area Remedial Investigation/ Feasibility Study Reports.

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Terms

CERCLA	<i>Comprehensive Environmental Response, Compensation, and Liability Act of 1980</i>
CHPRC	CH2M HILL Plateau Remediation Company
CZ	contaminated zone
DOE	U.S. Department of Energy
ECF	environmental calculation file
EPA	U.S. Environmental Protection Agency
HISI	Hanford Information Systems Inventory
K_d	distribution coefficient
PRG	preliminary remediation goal
RAO	remedial action objective
RDR/RAWP	remedial design report/remedial action work plan
RESRAD	RESidual RADioactivity code
RI/FS	remedial investigation/feasibility study
SICO	software installation and checkout
SZ	saturated zone
WAC	Washington Administrative Code
WDOH	Washington State Department of Health

1 Purpose

This Environmental Calculation documents assumptions and methods for development of radiological soil Preliminary Remediation Goals (PRGs) for the industrial worker exposure scenario for use in the 100 Areas and 300 Area Remedial Investigation/Feasibility Study (RI/FS) Reports. PRGs are concentration goals for a specific medium that are intended to protect specified receptors from exposure to contaminants through identified exposure pathways.

The PRGs described in the Environmental Calculation represent concentration goals in soil that are protective of a potential future industrial worker. The potentially complete exposure pathway associated with this scenario is the direct contact pathway. The PRGs described in this Environmental Calculation are generally consistent with the radiological remedial action goals for industrial land use described in DOE/RL-2001-47, *Remedial Design Report/Remedial Action Work Plan for the 300 Area (RDR/RAWP)*, except that exposure assumptions have been updated for consistency with recent 100 Area evaluations and to reflect current U.S. Environmental Protection Agency (EPA) guidance. Exposure assumptions that were updated include the inhalation rate, mass loading factor, exposure duration, external gamma shielding factor, indoor and outdoor time fractions, and soil ingestion rate. The PRGs were also updated from a protective level reflecting an annual dose rate of 15 millirem per year (mrem/yr) to a target risk of 1×10^{-4} . The exposure assumptions used to calculate the PRG values presented in this Environmental Calculation are described in Section 4.

2 Background

As described in DOE/RL-2008-46, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan* and DOE/RL-2009-30, *300 Area Decision Unit Remedial Investigation/Feasibility Study Work Plan*, the 100 Areas and 300 Area contain multiple source and groundwater operable units (OUs), that are part of the Hanford Site River Corridor, which encompasses approximately 570 km² (220 mi²) adjacent to the Columbia River. Cleanup levels corresponding to industrial land use in the River Corridor have been calculated in the DOE/RL-2001-47. For the purposes of developing PRGs within this Environmental Calculation document, the following target objectives are used¹:

- Prevent unacceptable risk to human health from exposure to soils and/or debris contaminated with radiological constituents less than 4.6 m (15 ft) bgs. PRGs for radionuclides that achieve this objective achieve the CERCLA risk range of 10^{-4} to 10^{-6} increased lifetime cancer risk consistent with EPA 540/R/99/006, *Radiation Risk Assessment At CERCLA Sites: Q & A*. As described in DOE/RL-2001-47, these PRGs are intended to limit radiation risks for 1,000 years following the completion of a remedial action. According to ANL/EAD-4, *User's Manual for RESRAD Version 6*, the 1,000-year timeframe ensures that the PRGs account for the decay of radionuclides to daughter products that are more radioactive.

This target objective has been developed only for the purpose of calculating PRGs that are presented in this Environmental Calculation. This target objective is not intended to supersede Remedial Action Objectives (RAOs) being developed as part of the 100 Areas and 300 Area RI/FS Reports. This Environmental Calculation document will be revised as needed to incorporate updates to these PRGs that may result from changes in RAOs occurring during development of the 100 Areas and 300 Area RI/FS Reports.

¹ The RAO used for calculating PRGs for purposes of this Environmental Calculation have been adapted from RAOs developed for the 300 Area, as presented in DOE/RL-2001-47.

3 Methodology

The radionuclide PRGs presented in this Environmental Calculation are single radionuclide soil concentrations corresponding to a target cancer risk level of 1×10^{-4} , 1×10^{-5} , and 1×10^{-6} which are protective of an industrial worker exposure scenario. These PRGs have been calculated using RESRAD (ANL 2009, *RESRAD for Windows, Version 6.5*). The RESRAD model and computer code was developed as a multifunctional tool to assist in developing cleanup criteria and assessing the dose or risk associated with residual radioactive material. The software application of RESRAD is presented in Section 5 of this Environmental Calculation.

The specific steps taken to calculate PRGs in soil using RESRAD are presented below:

1. Input the parameters from Tables 3-1 and 3-2 into RESRAD. Discussion of the assumptions used to develop these input parameters is presented in Section 4.
2. Input the arbitrary soil concentration of 1,000 pCi/g for a single radionuclide into RESRAD.
3. Input calculation times of 1, 3, 10, 30, 100, 300, and 1,000 years into RESRAD.
4. Run RESRAD and review the results to identify the year at which the peak cancer risk occurs; record the total cancer risk at the peak year associated with 1,000 pCi/g in the intermediate calculations worksheet (Attachment 1).
5. In the intermediate calculations worksheet (Attachment 1), estimate the concentration in soil required to achieve a 1×10^{-4} risk at the peak risk year; input that soil concentration into RESRAD; add the peak risk year to the calculation parameters.
6. Re-run RESRAD and verify that the estimated concentration corresponds to a 1×10^{-4} risk; perform additional iterations as needed to obtain a soil concentration that corresponds to 1×10^{-4} risk to within 1 percent (this is to allow rounding of the PRG value as appropriate), and record that concentration in the intermediate calculations worksheet (Attachment 1). Save the model inputs and outputs from the final run for documentation purposes (see Step 8 below).
7. Calculate concentrations in soil corresponding to 1×10^{-5} and 1×10^{-6} cancer risks. These are factors of 10 and 100 of the soil concentration corresponding to 1×10^{-4} cancer risk and can be calculated simply by division – this is done in the intermediate calculations worksheet (Attachment 1) and does not require re-running the model to obtain these values.
8. Document RESRAD results: save the input file (the *.RAD file) that corresponds to a risk of 1×10^{-4} with a unique file name identifying the project and radionuclide. An electronic copy of this file shall accompany this Environmental Calculation. Save the summary report (SUMMARY.REP) and the health risk report (INTRISK.REP) with unique file names – these files shall accompany this Environmental Calculation. The summary report contains the RESRAD input parameters; the health risk report presents the cancer risk estimates associated with the soil concentration at the PRG.
9. Repeat this process with the next radionuclide.

As an additional step to support the remedy selection process for uranium in 300 Area soils (DOE/RL-2010-99, *Remedial Investigation/Feasibility Study for the 300-FF-1, 300-FF-2, and 300-FF-5*), the RESRAD-calculated PRGs for the uranium isotopes are converted from activity-based concentrations (pCi/g) to mass-based concentrations (µg/kg) to facilitate development of a mass-based PRG for total uranium. The activity-based uranium isotope PRGs (pCi/g) are converted to mass-based PRGs (µg/kg) using the following equation (the conversion calculations are provided in Section 7).

$$\text{PRG } (\mu\text{g isotope/kg soil}) = [\text{PRG (pCi isotope/g soil)} / \text{Specific Activity (pCi isotope/g isotope)}] \times \frac{1 \times 10^6 (\mu\text{g isotope/g isotope}) \times 1000 (\text{g soil/kg soil})}{1} \quad (1)$$

Table 3-1. Input Parameter Values Used in RESRAD to Calculate Preliminary Remediation Goals in Soil for an Industrial Worker Exposure Scenario

RESRAD Category	Parameter	Units	User Input, Industrial Worker Direct Exposure	Rationale	Reference
Exposure Pathways	External gamma: Inhalation: Plant ingestion: Meat ingestion: Milk ingestion: Aquatic foods: Drinking water: Soil ingestion: Radon:	NA	Active Active Suppressed Suppressed Suppressed Suppressed Suppressed Active Suppressed		
R011 – Contaminated Zone (CZ)	Area of CZ	m ²	10,000	Generic site model ^a	
	Thickness of CZ	m	4.6	Direct exposure cleanup standards apply to the upper 4.6 m (15 ft) ^a	
	Length Parallel to Aquifer Flow	m	100	Square root of contaminated site area	
	Radiation Dose Limit	mrem/yr	Not used	EPA guidance. PRGs are calculated for target cancer risks.	EPA 540/R/99/006
	Elapsed Time of Waste Placement	yr	0	RESRAD default	
R012 –Principal Radionuclides Concentrations	All radionuclide contaminants of concern	pCi/g	Contaminant-specific	Contaminant-specific soil remedial action levels (pCi/g) are endpoints of the RESRAD calculations	
R013 - Cover and CZ Hydrological Data	Cover Depth	m	0	Generic site model ^a	
	Density of Cover Material	g/cm ³	Not used		
	Cover Erosion Rate	m/yr	Not used		
	Density of CZ	g/cm ³	1.6		DOE/RL-2001-47
	CZ Erosion Rate	m/yr	0.001	RESRAD default	

Table 3-1. Input Parameter Values Used in RESRAD to Calculate Preliminary Remediation Goals in Soil for an Industrial Worker Exposure Scenario

RESRAD Category	Parameter	Units	User Input, Industrial Worker Direct Exposure	Rationale	Reference
	CZ Total Porosity	Unitless	0.3		DOE/RL-2001-47
	CZ Field Capacity	Unitless	0.25		DOE/RL-2001-47
	CZ Hydraulic Conductivity	m/yr	0.0022		DOE/RL-2001-47
	CZ b Parameter	Unitless	15		DOE/RL-2001-47
	Humidity in Air	g/cm ³	8	RESRAD default	
	Evapotranspiration Coefficient	Unitless	0.91		Letter from EPA
	Wind Speed	m/s	3.4		DOE/RL-2001-47
	Precipitation	m/yr	0.16	Based on 16 cm (6.3 in.) average annual rainfall	DOE/RL-90-07
	Irrigation Rate	m/yr	0	Not applicable ^b	
	Irrigation Mode	NA	Overhead	RESRAD default	
	Runoff Coefficient	Unitless	0.2	RESRAD default	
	Watershed Area for Nearby Stream or Pond	m ²	Not used		
	Accuracy for Water/Soil Computations	Unitless	Not used		
R014 - Saturated Zone (SZ) Hydrological Data	Density of SZ	g/cm ³	NA	Not applicable ^b	
	SZ Total Porosity	Unitless	NA	Not applicable ^b	
	SZ Effective Porosity	Unitless	NA	Not applicable ^b	
	SZ Field Capacity	Unitless	NA	Not applicable ^b	
	SZ Hydraulic Conductivity	m/yr	NA	Not applicable ^b	
	SZ Hydraulic Gradient	Unitless	NA	Not applicable ^b	
	SZ b Parameter	Unitless	NA	Not applicable ^b	
	Water Table Drop Rate	m/yr	NA	Not applicable ^b	

Table 3-1. Input Parameter Values Used in RESRAD to Calculate Preliminary Remediation Goals in Soil for an Industrial Worker Exposure Scenario

RESRAD Category	Parameter	Units	User Input, Industrial Worker Direct Exposure	Rationale	Reference
	Well Pump Intake Depth	m below water table	NA	Not applicable ^b	
	Nondispersion (ND) or Mass-Balance (MB)	NA	NA	Not applicable ^b	
	Well Pumping Rate	m ³ /yr	NA	Not applicable ^b	
R015 - Uncontaminated and Unsaturated Strata Hydrological Data	Number of Unsaturated Strata	NA	NA	Not applicable ^b	
	Thickness	m	NA	Not applicable ^b	
	Soil Density	g/cm ³	NA	Not applicable ^b	
	Total Porosity	Unitless	NA	Not applicable ^b	
	Effective Porosity	Unitless	NA	Not applicable ^b	
	Field Capacity	Unitless	NA	Not applicable ^b	
	Soil-specific b Parameter	Unitless	NA	Not applicable ^b	
	Hydraulic Conductivity	m/yr	NA	Not applicable ^b	
R016 - Distribution Coefficients and Leach Rates	CZ K _d	mL/g	Contaminant-specific	Table 3-2.	K _d values (except for uranium) taken from DOE/RL-96-17, Table B-7 (RESRAD default used where no value is reported). Uranium K _d s taken from EPA, Ecology, and DOE, 2004.
	Leach Rate	yr ⁻¹	Contaminant-specific	RESRAD manual	Note - leach rates are not used; K _d values are used for all radionuclides for leaching calculations
	Saturated Solubility	mol/L	0	RESRAD default	Not used - K _d values are used for all leaching calculations

Table 3-1. Input Parameter Values Used in RESRAD to Calculate Preliminary Remediation Goals in Soil for an Industrial Worker Exposure Scenario

RESRAD Category	Parameter	Units	User Input, Industrial Worker Direct Exposure	Rationale	Reference
R017 - Inhalation and External Gamma	Inhalation Rate	m ³ /yr	7300	Average annual air intake based on a daily inhalation rate of 20 m ³ /day (365 days/yr).	OSWER Directive 9285.6-03
	Mass Loading for Inhalation	g/m ³	0.0001	WDOH guidance	WDOH/320-015
	Exposure duration	yr	25	EPA guidance	OSWER Directive 9285.6-03
	Indoor Dust Filtration Factor	Unitless	0.4	RESRAD default	
	External Gamma Shielding Factor	Unitless	0.4	EPA guidance	EPA/540-R-00-007, Equation 4
	Indoor Time Fraction	Unitless	0.17	Fraction of the year spent onsite indoors. Assumes 6 hr/day, 250 days/yr (1,500 hr/8,760 hr).	
	Outdoor Time Fraction	Unitless	0.057	Fraction of the year spent onsite outdoors. Assumes 2 hr/day, 250 days/yr (500 hr/8,760 hr).	
	Shape Factor	NA	Circular	RESRAD default	
R018 - Ingestion Pathway Data, Dietary Parameters	Fruits, Vegetables, and Grain Consumption	kg/yr	NA	Not applicable ^b	
	Leafy Vegetable Consumption	kg/yr	NA	Not applicable ^b	
	Milk Consumption	L/yr	NA	Not applicable ^b	
	Meat and Poultry Consumption	kg/yr	NA	Not applicable ^b	
	Fish Consumption	kg/yr	NA	Not applicable ^b	
	Other Seafood Consumption	kg/yr	NA	Not applicable ^b	

Table 3-1. Input Parameter Values Used in RESRAD to Calculate Preliminary Remediation Goals in Soil for an Industrial Worker Exposure Scenario

RESRAD Category	Parameter	Units	User Input, Industrial Worker Direct Exposure	Rationale	Reference
	Soil Ingestion	g/yr	18.25	Based on 50 mg/day x 365 days/yr	OSWER 9355.4-24
	Drinking Water Intake	L/yr	NA	Not applicable ^b	
	Drinking Water Contamination Fraction	Unitless	NA	Not applicable ^b	
	Household Water Contamination Fraction	Unitless	NA	Not applicable ^b	
	Livestock Water Contamination Fraction	Unitless	NA	Not applicable ^b	
	Irrigation Water Contamination Fraction	Unitless	NA	Not applicable ^b	
	Aquatic Food Contamination Fraction	Unitless	NA	Not applicable ^b	
	Plant Food Contamination Fraction	Unitless	NA	Not applicable ^b	
	Meat Contamination Fraction	Unitless	NA	Not applicable ^b	
	Milk Contamination Fraction	Unitless	NA	Not applicable ^b	
R019 - Ingestion Pathway Data, Nondietary	Livestock Fodder Intake for Meat	kg/d	NA	Not applicable ^b	
	Livestock Fodder Intake for Milk	kg/d	NA	Not applicable ^b	
	Livestock Water Intake for Meat	L/d	NA	Not applicable ^b	
	Livestock Water Intake for Milk	L/d	NA	Not applicable ^b	
	Livestock Intake of Soil	kg/d	NA	Not applicable ^b	
	Mass Loading for Foliar Deposition	g/m ³	NA	Not applicable ^b	

Table 3-1. Input Parameter Values Used in RESRAD to Calculate Preliminary Remediation Goals in Soil for an Industrial Worker Exposure Scenario

RESRAD Category	Parameter	Units	User Input, Industrial Worker Direct Exposure	Rationale	Reference
	Depth of Soil Mixing Layer	m	NA	Not applicable ^b	
	Depth of Roots	m	NA	Not applicable ^b	
R020 – Groundwater Usage	Groundwater Fractional Usage - Drinking Water	Unitless	NA	Not applicable ^b	
	Groundwater Fractional Usage - Household Usage	Unitless	NA	Not applicable ^b	
	Groundwater Fractional Usage - Livestock Water	Unitless	NA	Not applicable ^b	
	Groundwater Usage – Irrigation	Unitless	NA	Not applicable ^b	
R021 - Radon	Radon parameters are not used; Radon is not a Hanford Site contaminant of potential concern.			Not applicable ^b	

Notes:

- Generic site model parameters will be changed to site-specific values for cleanup verification.
- Not applicable – the following parameters are not used in the model when drinking water and food ingestion pathways are suppressed: contaminated zone hydrological data (R013), saturated zone hydrological data (R014) and uncontaminated, unsaturated strata hydrological data (R015), evapotranspiration rate and irrigation rate. These parameters are used in the model for estimating contaminant migration through soil and transport to groundwater, and are not used to develop Industrial Worker PRGs.

CZ = contaminated zone

EPA= U.S. Environmental Protection Agency

NA = not applicable

PRG = preliminary remediation goal

RESRAD= RESidual RADioactivity code (ANL 2009)

SZ = saturated zone

WDOH= Washington State Department of Health

ANL, 2009, RESRAD for Windows, Version 6.5.

DOE/RL-90-07, *Remedial Investigation/Feasibility Study Work Plan for the 100-BC-1 Operable Unit, Hanford Site, Richland, Washington.*DOE/RL-96-17, *Remedial Design Report/Remedial Action Work Plan for the 100 Area.*DOE/RL-2001-47, *Remedial Design Report/Remedial Action Work Plan for the 300 Area.*EPA/540-R-00-007, *Soil Screening Guidance for Radionuclides: User's Guide.*EPA 540/R/99/006, *Radiation Risk Assessment at CERCLA Sites: Q & A.*EPA, Ecology, and DOE, 2004, *Explanation of Significant Differences for the 300-FF-2 Operable Unit Record of*

Table 3-1. Input Parameter Values Used in RESRAD to Calculate Preliminary Remediation Goals in Soil for an Industrial Worker Exposure Scenario

RESRAD Category	Parameter	Units	User Input, Industrial Worker Direct Exposure	Rationale	Reference
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Decision.

OSWER Directive 9285.6-03, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final.*

OSWER 9355.4-24, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites.*

WDOH/320-015, *Hanford Guidance for Radiological Cleanup.*

Table 3-2. Radionuclide-Specific Distribution Coefficients

Radionuclide	K _d (cm ³ /g)	K _d Reference
Ag (silver)-108m	90	DOE/RL-96-17, Table B-7
Americium-241	200	DOE/RL-96-17, Table B-7
Carbon-14	200	DOE/RL-96-17, Table B-7
Cesium-137	50	DOE/RL-96-17, Table B-7
Cobalt-60	50	DOE/RL-96-17, Table B-7
Curium-243	200	DOE/RL-96-17, Table B-7
Curium-244	200	DOE/RL-96-17, Table B-7
Curium-245	200	DOE/RL-96-17, Table B-7
Europium-152	200	DOE/RL-96-17, Table B-7
Europium-154	200	DOE/RL-96-17, Table B-7
Europium-155	200	DOE/RL-96-17, Table B-7
Iodine-129	1	DOE/RL-96-17, Table B-7
Neptunium-237	15	DOE/RL-96-17, Table B-7
Nickel-59	30	DOE/RL-96-17, Table B-7
Nickel-63	30	DOE/RL-96-17, Table B-7
Niobium-94	200	DOE/RL-96-17, Table B-7
Plutonium-238	200	DOE/RL-96-17, Table B-7
Plutonium-239/240	200	DOE/RL-96-17, Table B-7
Plutonium-241	200	DOE/RL-96-17, Table B-7
Potassium-40	5.5	DOE/RL-96-17, Table B-7
Radium-226	200	DOE/RL-96-17, Table B-7
Radium-228	200	DOE/RL-96-17, Table B-7
Strontium-90	25	DOE/RL-96-17, Table B-7
Technetium-99	0	DOE/RL-96-17, Table B-7
Thorium-228	200	DOE/RL-96-17, Table B-7
Thorium-230	200	DOE/RL-96-17, Table B-7
Thorium-232	200	DOE/RL-96-17, Table B-7
Tritium (H-3)	0	DOE/RL-96-17, Table B-7
Uranium-233/234	8.9	EPA, Ecology, and DOE, 2004
Uranium-234	8.9	EPA, Ecology, and DOE, 2004
Uranium-235	8.9	EPA, Ecology, and DOE, 2004

Table 3-2. Radionuclide-Specific Distribution Coefficients

Radionuclide	K _d (cm ³ /g)	K _d Reference
Uranium-238	8.9	EPA, Ecology, and DOE, 2004
Daughter Radionuclides (included automatically by RESRAD with selection of parent)		
Actinium-227	20	RESRAD default
Americium-243	200	DOE/RL-96-17, Table B-7
Gadolinium-152 ^a	-1	RESRAD default
Lead-210	100	RESRAD default
Plutonium-240	200	DOE/RL-96-17, Table B-7
Protactinium-231	50	RESRAD default
Thorium-229	200	DOE/RL-96-17, Table B-7
Uranium-236	8.9	EPA, Ecology, and DOE, 2004

Notes:

- a. RESRAD displays a default value of -1 on the K_d input screen for gadolinium-152 indicating the K_d value is derived internally by the code.

K_d = distribution coefficient

RESRAD = RESidual RADioactivity code (ANL 2009)

ANL, 2009, RESRAD for Windows, Version 6.5.

DOE/RL-96-17, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*.

EPA, Ecology, and DOE, 2004, *Explanation of Significant Differences for the 300-FF-2 Operable Unit Record of Decision*.

4 Assumptions and Inputs

The inputs used in the RESRAD code to calculate radiological PRGs in soil for an industrial worker exposure scenario are presented in Table 3-1. The key assumptions associated with these inputs are discussed below. The inputs are generally consistent with those used for evaluation of the industrial land-use scenario in the 300 Area RDR/RAWP (DOE/RL-2001-47) but have been revised for several parameters as noted below.

- The potentially complete exposure routes considered are for a future adult industrial worker and consist of external gamma exposure, inhalation of dust, and incidental soil ingestion.
- Drinking water will not be obtained from groundwater sources, food products will not be grown on-site, and water will not be applied to the site for irrigation purposes.
- The period of analysis is 1,000 years, which is considered a reasonable endpoint for radiological risk calculations. The peak risk for most radionuclides occurs in less than 1,000 years.
- Direct exposure of an onsite worker to radionuclides in soil to a depth of 4.6 m (15 ft) may occur. This represents a reasonable estimate of the depth of soil that could be excavated and distributed at the soil surface as a result of site development activities. When the worker is outdoors, it is assumed that clean fill does not provide shielding from radiation (cover depth is zero).
- Parameters associated with the generic site model (e.g., contaminated zone area and thickness, cover depth), soil hydrological properties, and meteorological conditions are consistent with those identified in DOE/RL-2001-47 except the precipitation rate was revised from 0.1524 m/yr to 0.16 m/yr for consistency with recent 100 Area evaluations.
- K_d values (except for uranium isotopes) were taken from the 100 Area RDR/RAWP (DOE/RL-96-17), which provides values consistent with DOE/RL-2001-47 and includes a larger list of radionuclides. K_d values for uranium isotopes were taken from EPA, Ecology, and DOE, 2004, *Explanation of Significant Differences for the 300-FF-2 Operable Unit Record of Decision*. For radionuclides not included in DOE/RL-96-17, the RESRAD default value was used. The K_d values are summarized in Table 3-2.
- The exposure duration was revised from 30 years to 25 years, consistent with EPA guidance in OSWER Directive 9285.6-03, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final*.
- The inhalation rate was revised from 8,400 m³/yr (RESRAD default) to 7,300 m³/yr, consistent with EPA guidance in OSWER Directive 9285.6-03 (based on 20 m³/day × 365 days/yr). The mass loading for inhalation factor was revised from 0.0002 g/m³ to 0.0001 g/m³, consistent with Washington State Department of Health (WDOH) guidance in WDOH/320-015, *Hanford Guidance for Radiological Cleanup*.
- The external gamma shielding factor was revised from 0.7 (RESRAD default) to 0.4, consistent with EPA guidance in EPA/540-R-00-007, *Soil Screening Guidance for Radionuclides: User's Guide*. The shielding factor is the fraction of outdoor gamma radiation that will be available indoors (the lower the factor the higher the building's shielding).
- The worker is onsite 8 hours per day (6 hours indoors, 2 hours outdoors) for 250 days per year. The indoor time fraction (fraction of the year spent indoors onsite) was revised from 0.165 to 0.17 based

on $6 \text{ hr/day} \times 250 \text{ days/yr} \div 8,760 \text{ hr/yr}$. The outdoor time fraction (fraction of the year spent outdoors onsite) was revised from 0.055 to 0.057 based on $2 \text{ hr/day} \times 250 \text{ days/yr} \div 8,760 \text{ hr/yr}$.

- The soil ingestion rate was revised from 25 g/yr to 18.25 g/yr, consistent with EPA guidance in OSWER 9355.4-24, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*. The annual rate is based on $50 \text{ mg/day} \times 365 \text{ days/yr}$. RESRAD uses a yearly rate and automatically adjusts (based on area, occupancy, and cover factors) to account only for the contaminated source.
- The health protective level for each PRG was revised from a level reflecting an annual dose rate of 15 mrem/yr to a target cancer risk of 1×10^{-4} , consistent with EPA guidance in EPA 540/R/99/006.
- The specific activities used with Equation 1 to convert uranium isotope PRGs from activity-based concentrations (pCi/g) to mass-based concentrations ($\mu\text{g/kg}$) are shown in Table 4-1.

Table 4-1. Uranium Isotope Specific Activities

Isotope	Specific Activity (Bq/g) ^a	Conversion Factor (Bq/Ci)	Conversion Factor (pCi/Ci)	Specific Activity (pCi/g) ^b
Uranium-233/234	2.302E+08	3.70E+10	1.00E+12	6.222E+09
Uranium-234	2.302E+08	3.70E+10	1.00E+12	6.222E+09
Uranium-235	7.995E+04	3.70E+10	1.00E+12	2.161E+06
Uranium-238	1.243E+04	3.70E+10	1.00E+12	3.359E+05

a. *Table of Isotopes 8th Edition, 1995, Last update 12th April, 1998.*

b. Formula = Specific Activity (Bq/g) / Conversion Factor (Bq/Ci) x Conversion Factor (pCi/Ci)

5 Software Applications

RESRAD is approved for use by CH2M HILL Plateau Remediation Company (CHPRC) at the Hanford Site in accordance with the requirements of PRC-PRO-IRM-309, *Controlled Software Management*. All supporting calculations were performed on electronic spreadsheets using Microsoft Excel².

5.1 Description

The following presents the description of RESRAD used for this Environmental Calculation. See CHPRC-00209, *RESRAD Software Management Plan* for further details regarding the use of this software:

- RESRAD for Windows,
- Version 6.5, Created October 30, 2009
- HISI Identification Number: 2102
- Workstation type and property number: 0075 Freestone Environmental Property Tag and WC95091.

² Excel is a trademark of Microsoft Corporation, Redmond, Washington.

5.2 Software Installation and Checkout

The software installation and checkout form for RESRAD is attached to this Environmental Calculation.

5.3 Statement of Valid Software Application

The following presents the statement that RESRAD is a valid software application.

- RESRAD was developed for DOE to assist in developing cleanup criteria and assessing the dose or risk associated with residual radioactive material. RESRAD has been used for this purpose in support of previous decision documents developed at the Hanford Site.
- RESRAD as it has been used in this Environmental Calculation has been implemented within the range of its limitations. The parameters used in the modeling (shown in Table 3-1) are presented in the modeling input files accompanying this Environmental Calculation, and also in the modeling output files where they are shown alongside the default parameters provided with the model. As discussed in Section 7, a sensitivity analysis of selected parameters has been performed to evaluate the effects of variations in input values on model results.

6 Calculation

Radiological soil PRGs protective of an industrial worker exposure scenario are calculated with RESRAD using the methodology described in Section 3 and the assumptions and inputs described in Section 4. Model execution was checked by verifying that identical output could be obtained when the input files were run with RESRAD installed on a separate workstation. Supporting calculations are contained in the Excel workbook “ECF-HANFORD-10-0452 IW Rad PRGs Attachments”. This workbook contains the following worksheets:

- Attachment 1 - Intermediate Calculations for RESRAD; shows the steps used in calculating PRGs for protection of human health from direct contact with soil for an industrial worker exposure scenario. Summarized in Table 7-1.
- Attachment 2 – Sensitivity Analysis (site area); shows the change in PRGs for protection of human health from direct contact with soil with changes in the surface area of the site. Summarized in Table 7-2.
- Attachment 3 – Sensitivity Analysis (site thickness); shows the change in PRGs for protection of human health from direct contact with soil with changes in the thickness of contamination in the site. Summarized in Table 7-3.

Input and output files from RESRAD are organized as follows:

- Input files are grouped into the folder “Industrial Worker RESRAD Inputs.zip”
- Output files are grouped into the folder “Industrial Worker RESRAD Outputs.zip”

CHPRC Software Installation and Checkout (SICO) forms are contained in the following files:

- SICO – Ross.pdf
- SICO – Singleton.pdf

7 Results/Conclusions

Results of the industrial worker PRG calculations for target cancer risk levels of 1×10^{-4} , 1×10^{-5} , and 1×10^{-6} are summarized in Table 7-1. PRGs for protection of human health from direct contact with radionuclides in soil are based on the year that the peak risk occurs, within a 1,000 year timeframe. For most of the radionuclides examined, this occurs during year zero (Attachment 1). The year with the peak risk for Cm-245, Pu-241, Th-230, Th-232, and U-233/234 occurs later, because of the contribution to risk from the ingrowth of daughter products.

A sensitivity analysis was conducted to evaluate the protectiveness of the PRGs with changes in the area of the contaminated zone assumed in RESRAD. The sensitivity analysis involved calculating PRGs using 1,000 m², 10,000 m² (the base case), and 100,000 m² areas for the assumed contaminated site area. The results of this analysis are summarized in Table 7-2. The results from this sensitivity analysis show that the PRGs are protective for all waste sites with contamination areas smaller than the 10,000 m² assumed in these calculations. This analysis indicates that calculated PRGs are not sensitive to small changes in waste site surface area. However, with an assumed site area of 100,000 m², calculated PRGs would be from 4% to 11% lower than the values calculated for the base case (as presented in Table 7-2). Further details are provided in the Attachment 2. These PRGs are suitable for remedial planning purposes for all waste sites; decisions to recalculate these values to accommodate site areas larger than 10,000 m² should be made on a project-specific basis.

A sensitivity analysis was conducted to evaluate the protectiveness of the PRGs with changes in the thickness of contaminated zone assumed in RESRAD. This sensitivity analysis involved calculating PRGs using 1 m, 4.6 m (the base case), and 10 m thicknesses for the assumed contaminated site. The results of this analysis are summarized in Table 7-3. Further details are provided in Attachment 3. The results from this analysis show that the calculated PRGs are insensitive to the thickness of contamination, and that these PRGs should be applicable for remedial planning purposes for all waste sites; decisions to recalculate these values to accommodate thicknesses of contamination different from the base case value (4.6 m) should be made on a project-specific basis.

To provide a PRG for total uranium for use in the 300 Area Feasibility Study (DOE/RL-2010-99), the RESRAD-calculated PRGs for the uranium isotopes are converted from activity-based concentrations (pCi/g) to mass-based concentrations (μg/kg), as shown in Table 7-4. The conversions are made using the PRGs protective at the 1×10^{-4} risk level, which represents the upper threshold of the U.S. Environmental Protection Agency (EPA) target risk range of 1×10^{-4} to 1×10^{-6} . To determine an appropriate PRG for total uranium from the mass-based uranium isotope PRGs shown in Table 7-4, consideration is given to the mass fractions of the uranium isotopes in total uranium. For the purposes of this Environmental Calculation, uranium isotope mass fractions are calculated based on the Hanford Site uranium soil background concentrations reported in DOE/RL-96-12, *Hanford Site Soil Background: Part 2, Soil Background for Radioactive Analytes*. The mass fractions are calculated by converting each isotope's reported activity-based background concentration to a mass-based concentration, as shown in Table 7-5. This table shows that by mass, uranium-238 comprises over 98% of the total uranium soil background concentration. The mass-based PRG for uranium-238 of 842,397 μg/kg is therefore recommended for use as a PRG for total uranium. Use of the uranium-238 value is considered conservative in that the uranium-238 value is lower than the total uranium PRG value would be if uranium-233/234 and uranium-235 were also included.

Table 7-1. Summary of Preliminary Remediation Goals for the 100 Areas and 300 Area Industrial Worker Exposure Scenario

Radionuclide	Selected Radionuclide Direct Exposure PRG at 10^{-4} Risk Level (pCi/g)	Selected Radionuclide Direct Exposure PRG at 10^{-5} Risk Level (pCi/g)	Selected Radionuclide Direct Exposure PRG at 10^{-6} Risk Level (pCi/g)
Ag (silver)-108m	5.1	0.51	0.051
Americium-241	942	94	9.4
Carbon-14	1.60E+06	160,000	16,000
Curium-243	105	11	1.1
Curium-244	7,200	720	72
Curium-245	131	13	1.3
Cobalt-60	9.4	0.94	0.094
Cesium-137	18	1.8	0.18
Europium-152	12	1.2	0.12
Europium-154	13	1.3	0.13
Europium-155	966	97	9.7
Tritium (H-3)	49,800	4,980	498
Iodine-129	1,943	194	19
Potassium-40	43	4.3	0.43
Niobium-94	4.7	0.47	0.047
Nickel-59	2.44E+06	244,200	24,420
Nickel-63	1.10E+06	110,000	11,000
Neptunium-237	42	4.2	0.42
Plutonium-238	3,370	337	34
Plutonium-239/240 ^a	2,906	291	29
Plutonium-241	31,100	3,110	311
Radium-226	4.0	0.40	0.040
Radium-228	8.8	0.88	0.088
Strontium-90	1,968	197	20
Technetium-99	165,700	16,570	1,657
Thorium-228	40	4.0	0.40
Thorium-230	12	1.2	0.12
Thorium-232	2.7	0.27	0.027
Uranium-233/234 ^b	1,757	176	18
Uranium-234	1,757	176	18

Table 7-1. Summary of Preliminary Remediation Goals for the 100 Areas and 300 Area Industrial Worker Exposure Scenario

Radionuclide	Selected Radionuclide Direct Exposure PRG at 10^{-4} Risk Level (pCi/g)	Selected Radionuclide Direct Exposure PRG at 10^{-5} Risk Level (pCi/g)	Selected Radionuclide Direct Exposure PRG at 10^{-6} Risk Level (pCi/g)
Uranium-235	61	6.1	0.61
Uranium-238	283	28	2.8

Notes:

- a. Values presented are calculated for plutonium-239; plutonium-239 is assumed to be the dominant isotope in undifferentiated plutonium-239/240.
- b. Values presented are calculated for Uranium-234; uranium-234 is assumed to be the dominant isotope in undifferentiated uranium-233/234.

PRG = preliminary remediation goal

Table 7-2. Variation in Preliminary Remediation Goals with Variation in Contaminated Zone Area, Industrial Worker Exposure Scenario

Radionuclide	Selected Radionuclide PRG (pCi/g) at a 10^{-4} Target Risk Level by Contaminated Zone Area		
	1,000 m ²	10,000 m ²	100,000 m ²
Americium-241	1,003	942	897
Cesium-137	19	18	17
Plutonium-239/240	3,226	2,906	2,590
Radium-226	4.2	4.0	3.8

Table 7-3. Variation in Preliminary Remediation Goals with Variation in Contaminated Zone Thickness, Industrial Worker Exposure Scenario

Radionuclide	Selected Radionuclide PRG (pCi/g) at a 10^{-4} Target Risk Level by Contaminated Zone Thickness		
	1 m	4.6 m	10 m
Americium-241	942	942	941
Cesium-137	18	18	18
Plutonium-239/240	2,908	2,906	2,906
Radium-226	4.0	4.0	4.0

Table 7-4. Conversion from Activity- to Mass-Based PRG for Uranium Isotopes

Uranium Isotope	Industrial Worker PRG at 10 ⁻⁴ Risk Level (pCi isotope/g soil) ^a	Specific Activity (pCi isotope/g isotope) ^b	Conversion Factor (μg isotope/g isotope)	Conversion Factor (g soil/kg soil)	Industrial Worker PRG at 10 ⁻⁴ Risk Level (μg isotope/kg soil) ^c
U-233/234	1,757	6.222E+09	1,000,000	1,000	282
U-234	1,757	6.222E+09	1,000,000	1,000	282
U-235	61	2.161E+06	1,000,000	1,000	28,230
U-238	283	3.359E+05	1,000,000	1,000	842,397

a. See Table 7-1.

b. See Table 4-1.

c. Calculated using Equation 1 (see Section 3).

Table 7-5. Calculation of Uranium Isotope Mass Fractions

Uranium Isotope	Background Activity (pCi isotope/g soil) ^a	Activity Fraction	Specific Activity (pCi isotope/g isotope) ^b	Background Mass (μg isotope/kg soil) ^c	Mass Fraction
U-233/234	1.10	0.458	6.222E+09	0.177	0.00006
U-234	1.10	0.458	6.222E+09	0.177	0.00006
U-235	0.11	0.048	2.161E+06	50.4	0.016
U-238	1.06	0.467	3.359E+05	3155	0.98

a. DOE/RL-96-12, *Hanford Site Soil Background: Part 2, Soil Background for Radioactive Analytes*.

b. See Table 4-1.

c. Formula = Background Activity (pCi/g) / Specific Activity (pCi/g) x 1E+06 (μg/g) x 1E+03 (g/kg)

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Attachment 1
Intermediate Calculations

Radionuclide	Input Conc (pCi/g)	Risk	Time of Max Risk (yr)	Target Risk	Estimated concentration at 10 ⁻⁴ target risk (pCi/g)	Concentration Input to RESRAD (pCi/g)	Calculated Cancer Risk from RESRAD	Percent Difference in Risk Between Estimated and Input Concentrations	Final PRG (pCi/g)	Target Risk
Ag-108	1000	9.670E-02	0	1.00E-04	1.03	5.1	1.003E-04	0.2991%	5.1 1 0.1	1.00E-04 1.00E-05 1.00E-06
Am-241	1000	1.062E-04	0	1.00E-04	941.62	942	1.001E-04	0.0999%	942 94 9.4	1.00E-04 1.00E-05 1.00E-06
C-14	1000	6.301E-08	0	1.00E-04	1587049.67	1600000	1.008E-04	0.7937%	1600000 160000 16000.0	1.00E-04 1.00E-05 1.00E-06
Co-60	1000	1.068E-02	0	1.00E-04	9.36	9.4	1.004E-04	0.3984%	9.4 1 0.1	1.00E-04 1.00E-05 1.00E-06
Cs-137	1000	5.656E-03	0	1.00E-04	17.68	17.7	1.001E-04	0.0999%	17.7 2 0.2	1.00E-04 1.00E-05 1.00E-06
Cm-243	1000	9.515E-04	0	1.00E-04	105.10	105	9.991E-05	-0.0901%	105 11 1.1	1.00E-04 1.00E-05 1.00E-06
Cm-244	1000	1.390E-05	0	1.00E-04	7194.24	7200	1.001E-04	0.0999%	7200 720 72.0	1.00E-04 1.00E-05 1.00E-06
Cm-245	1000	7.618E-04	575	1.00E-04	131.27	131	9.980E-05	-0.2004%	131 13 1.3	1.00E-04 1.00E-05 1.00E-06
Eu-152	1000	8.736E-03	0	1.00E-04	11.45	11.5	1.005E-04	0.4975%	11.5 1 0.1	1.00E-04 1.00E-05 1.00E-06
Eu-154	1000	7.499E-03	0	1.00E-04	13.34	13.3	9.973E-05	-0.2707%	13.3 1 0.1	1.00E-04 1.00E-05 1.00E-06
Eu-155	1000	1.035E-04	0	1.00E-04	966.18	966	9.994E-05	-0.0600%	966 97 9.7	1.00E-04 1.00E-05 1.00E-06
H-3	1000	2.008E-06	0	1.00E-04	49800.80	49800	9.999E-05	-0.0100%	49800 4980 498.0	1.00E-04 1.00E-05 1.00E-06

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Radionuclide	Input Conc (pCi/g)	Risk	Time of Max Risk (yr)	Target Risk	Estimated concentration at 10 ⁻⁴ target risk (pCi/g)	Concentration Input to RESRAD (pCi/g)	Calculated Cancer Risk from RESRAD	Percent Difference in Risk Between Estimated and Input Concentrations	Final PRG (pCi/g)	Target Risk
I-129	1000	5.147E-05	0	1.00E-04	1942.88	1943	1.000E-04	0.0000%	1943 194 19.4	1.00E-04 1.00E-05 1.00E-06
K-40	1000	2.339E-03	0	1.00E-04	42.75	43	1.006E-04	0.5964%	43 4.3 0.43	1.00E-04 1.00E-05 1.00E-06
Nb-94	1000	2.135E-02	0	1.00E-04	4.68	4.7	1.004E-04	0.3984%	5 0.5 0.047	1.00E-04 1.00E-05 1.00E-06
Ni-59	1000	4.095E-08	0	1.00E-04	2442002.44	2442000	9.828E-05	-1.7501%	2442000 244200.0 24420	1.00E-04 1.00E-05 1.00E-06
Ni-63	1000	9.157E-08	0	1.00E-04	1092060.72	1100000	1.007E-04	0.6951%	1100000 110000.0 11000	1.00E-04 1.00E-05 1.00E-06
Np-237	1000	2.373E-03	0	1.00E-04	42.14	42.1	9.992E-05	-0.0801%	42 4.2 0.421	1.00E-04 1.00E-05 1.00E-06
Pu-241	1000	3.214E-06	57	1.00E-04	31113.88	31100	9.995E-05	-0.0500%	31100 3110.0 311	1.00E-04 1.00E-05 1.00E-06
Pu-238	1000	2.967E-05	0	1.00E-04	3370.41	3370	9.999E-05	-0.0100%	3370 337.0 33.7	1.00E-04 1.00E-05 1.00E-06
Pu-239/240 ^b	1000	3.441E-05	0	1.00E-04	2906.13	2906	9.998E-05	-0.0200%	2906 290.6 29.06	1.00E-04 1.00E-05 1.00E-06
Ra-226	1000	2.499E-02	0	1.00E-04	4.00	4	9.995E-05	-0.0500%	4 0.4 0.04	1.00E-04 1.00E-05 1.00E-06
Ra-228	1000	1.131E-02	0	1.00E-04	8.84	8.84	9.999E-05	-0.0100%	9 0.9 0.0884	1.00E-04 1.00E-05 1.00E-06
Sr-90	1000	5.081E-05	0	1.00E-04	1968.12	1968	9.999E-05	-0.0100%	1968 196.8 19.68	1.00E-04 1.00E-05 1.00E-06
Tc-99	1000	6.035E-07	0	1.00E-04	165700.08	165700	9.999E-05	-0.0100%	165700 16570.0 1657	1.00E-04 1.00E-05 1.00E-06

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Radionuclide	Input Conc (pCi/g)	Risk	Time of Max Risk (yr)	Target Risk	Estimated concentration at 10 ⁻⁴ target risk (pCi/g)	Concentration Input to RESRAD (pCi/g)	Calculated Cancer Risk from RESRAD	Percent Difference in Risk Between Estimated and Input Concentrations	Final PRG (pCi/g)	Target Risk
Th-228	1000	2.535E-03	0	1.00E-04	39.45	39.5	1.002E-04	0.1996%	40	1.00E-04
									4.0	1.00E-05
									0.395	1.00E-06
Th-230	1000	8.636E-03	1000	1.00E-04	11.58	11.6	1.002E-04	0.1996%	12	1.00E-04
									1.2	1.00E-05
									0.116	1.00E-06
Th-232	1000	3.643E-02	65	1.00E-04	2.74	2.74	9.981E-05	-0.1904%	3	1.00E-04
									0.3	1.00E-05
									0.0274	1.00E-06
U-233/234 ^a	1000	5.692E-05	1000	1.00E-04	1756.85	1757	1.000E-04	0.0000%	1757	1.00E-04
									175.7	1.00E-05
									17.57	1.00E-06
U-234	1000	5.692E-05	1000	1.00E-04	1756.85	1757	1.000E-04	0.0000%	1757	1.00E-04
									175.7	1.00E-05
									17.57	1.00E-06
U-235	1000	1.629E-03	0	1.00E-04	61.39	61.4	1.000E-04	0.0000%	61	1.00E-04
									6.1	1.00E-05
									0.614	1.00E-06
U-238	1000	3.532E-04	0	1.00E-04	283.13	283	9.996E-05	-0.0400%	283	1.00E-04
									28.3	1.00E-05
									2.83	1.00E-06

a. Values presented are calculated for plutonium-239; plutonium-239 is assumed to be the dominant isotope in undifferentiated plutonium-239/240

b. Values presented are calculated for Uranium-234; uranium-234 is assumed to be the dominant isotope in undifferentiated uranium-233/234

Attachment 2
Site Area Sensitivity Analysis

Radionuclide	Input Conc (pCi/g)	Risk	Time of Max Risk (yr)	Surface Area (m ²)	Target Risk	Estimated concentration at 10 ⁻⁴ target risk (pCi/g)	Concentration Input to RESRAD (pCi/g)	Calculated Cancer Risk from RESRAD	Percent Difference in Risk Between Estimated and Input Concentrations	Percent Difference in PRGs Between Base Case (10,000 m ²) and Alternate Site Areas
Am-241	1000	1.062E-04	0	10,000	1.00E-04	941.62	942	1.001E-04	0.0999%	
	1000	1.115E-04	0	100,000	1.00E-04	896.86	897	1.00E-04	-0.0100%	4.8%
	1000	9.972E-05	0	1,000	1.00E-04	1002.81	1003	1.000E-04	0.0000%	-6.5%
Cs-137	1000	5.656E-03	0	10,000	1.00E-04	17.68	17.7	1.001E-04	0.0999%	
	1000	5.916E-03	0	100,000	1.00E-04	16.90	16.9	1.00E-04	-0.0200%	4.5%
	1000	5.360E-03	0	1,000	1.00E-04	18.66	18.7	1.002E-04	0.1996%	-5.6%
Pu-239/240	1000	3.441E-05	0	10,000	1.00E-04	2906.13	2906	9.998E-05	-0.0200%	
	1000	3.861E-05	0	100,000	1.00E-04	2590.00	2590	1.00E-04	0.0000%	10.9%
	1000	3.100E-05	0	1,000	1.00E-04	3225.81	3226	1.000E-04	0.0000%	-11.0%
Ra-226	1000	2.499E-02	0	10,000	1.00E-04	4.00	4	1.00E-04	-0.0500%	
	1000	2.601E-02	0	100,000	1.00E-04	3.84	3.84	9.99E-05	-0.1201%	4.0%
	1000	2.382E-02	0	1,000	1.00E-04	4.20	4.2	1.000E-04	0.0000%	-5.0%

Attachment 3
Site Thickness Sensitivity Analysis

Radionuclide	Input Conc (pCi/g)	Risk	Time of Max Risk (yr)	Site Thickness (m)	Target Risk	Estimated concentration at 10 ⁻⁴ target risk (pCi/g)	Concentration Input to RESRAD (pCi/g)	Calculated Cancer Risk from RESRAD	Percent Difference in Risk Between Estimated and Input Concentrations	Percent Difference in PRGs Between Base Case (4.6 m) and Alternate Site Areas
Am-241	1000	1.062E-04	0	4.6	1.00E-04	941.62	942	1.001E-04	0.0999%	
	1000	1.063E-04	0	10	1.00E-04	940.73	941	1.00E-04	-0.0200%	0.1%
	1000	1.062E-04	0	1	1.00E-04	941.62	942	1.001E-04	0.0999%	0.0%
Cs-137	1000	5.656E-03	0	4.6	1.00E-04	17.68	17.7	1.001E-04	0.0999%	
	1000	5.657E-03	0	10	1.00E-04	17.68	17.7	1.00E-04	0.1996%	0.0%
	1000	5.649E-03	0	1	1.00E-04	17.70	17.7	9.999E-05	-0.0100%	0.0%
Pu-239/240	1000	3.441E-05	0	4.6	1.00E-04	2906.13	2906	9.998E-05	-0.0200%	
	1000	3.441E-05	0	10	1.00E-04	2906.13	2906	1.00E-04	-0.0200%	0.0%
	1000	3.439E-05	0	1	1.00E-04	2907.82	2908	1.000E-04	0.0000%	-0.1%
Ra-226	1000	2.499E-02	0	4.6	1.00E-04	4.00	4	1.00E-04	-0.0500%	
	1000	2.499E-02	0	10	1.00E-04	4.00	4	9.996E-05	-0.0400%	0.0%
	1000	2.498E-02	0	1	1.00E-04	4.00	4	9.992E-05	-0.0801%	0.0%